Advanced Physics- Based Modeling of Discrete Clutter and Diffuse Reverberation in the Littoral Environment

STTR Phase I - Topic N03-T011

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14. ABSTRACT
The proposed Phase II tasking will allow the model to be developed into a mature, configuration managed modeling product. The Phase II tasks include the continuation of the acoustic data analyses by Charles Holland at ARL/PSU for the development of additional understanding and modeling for various geoclutter mechanisms. Additional task will include the additional model development at NRL-DC by Kevin LePage and specifically the implementation of the modeling for the identified geoclutter mechanisms from Charles Holland. The acoustic data sets identified for model-to-data comparison by ARL/PSU will be used to provide feedback to NRL-DC for additional model upgrades. A final task for the Phase II base program will be to produce a configuration managed version of the model with corresponding documentation. All four tasks proposed for the Phase II base program have a 24 month period of performance.

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Phase I Goals and Summary of Phase I Technical Accomplishments

The goals of the Phase I STTR tasks were to identify the key discrete clutter mechanisms identified in the research to date and to report on the current state-of-the-art in diffuse reverberation and discrete clutter modeling. The challenges for active ASW sonar systems include the problems of discrete clutter and diffuse bottom reverberation. Diffuse bottom reverberation, at present, is the better understood of the two. The problem of understanding and modeling discrete clutter is now coming to the forefront as the Navy operates their active sonar systems more often in littoral areas.

The Phase I findings illustrate both the depth of the current understanding of the physical mechanisms that cause discrete clutter for active ASW sonar systems and the ability to simulate broadband discrete clutter time series. The results showing the target-like returns from mud volcanoes in the Malta Plateau illustrate both the degree to which the physical mechanisms behind geoclutter are understood and the likelihood that many other mechanisms are not even known, like mud volcanoes were just a few years ago. As has been stated at the outset of this work, only a subset of mechanisms responsible for target-like clutter are currently known and a subset of those mechanisms known are understood to the degree that they can be modeled.

The survey of the current reverberation model reveals that the two Navy standard performance prediction models, ASPM and CASS, each are unsuitable candidates for a starting point for the Phase II work. SST is a very capable simulation package but is unfortunately tailored for the high-frequency community with its use of the GRAB eigenray propagation loss model. As the lead developer of SST noted, “Farther reaching changes would extend SST’s applicability down to lower frequencies. A bottom model with penetration to sub-bottom layers would be a good start. A more radical change would be to incorporate some form of Parabolic Equation (PE) or other wave-based propagation model.” The task of modifying SST for low-frequency simulations would be larger in size than could be done under the scope of the Phase II funding.

The research by Chris Harrison and Kevin LePage each present some unique capabilities for computing diffuse reverberation. The analytic predictions developed by Chris Harrison and the SUPREMO tool developed at SACLANTCEN each will require additional modifications to extend their capability into predictions in the time series domain. The model approach developed by Kevin LePage during his time at SACLANTCEN and NRL-DC is suitable to the problem of directly modeling reverberation time series in the low to mid frequency range. The approach developed by Kevin LePage relies on the fact that normal mode methods are directly applicable for predicting time series in narrow bands (approximately one tenth of the center frequency) to efficiently predict reverberation from arbitrary distributions (realizations) of scatterers. The extension to bistatic geometries and more general environments is expected to be a relatively straightforward process. The modeling approach developed by Kevin LePage is recommended for further development in the Phase I option and the Phase II plan.

Applications of this proposed simulation product have been identified within both the AEER and LAMP program in a meeting with representatives of these programs. At the end of the Phase I base program, the goal of a physics-based simulation of broadband time series including both discrete clutter and diffuse reverberation for frequencies below 5 KHz is attainable.

Phase II Tasks (Estimate of Technical Feasibility)

With a recommendation made for the modeling approach to be further developed under the Phase I option and the Phase II plan, the future tasks can now be defined more clearly than at the start of the Phase I tasks. The Phase I option to be carried out over three months following the completion of the Phase I base program will work to identify in-water data sets for testing of the model during the Phase II tasking, identify the interface requirements for the use of the Phase II simulation by the EER and LAMP program, begin work on the documentation for the simulation and continue modifying the Kevin LePage's model to satisfy the requirements of the simulation.

The proposed Phase II tasking will allow the model to be developed into a mature, configuration managed modeling product. The Phase II tasks include the continuation of the acoustic data analyses by Charles Holland at ARL/PSU for the development of additional understanding and modeling for various geoclutter mechanisms. Additional task will include the additional model development at NRL-DC by Kevin LePage and specifically the implementation of the modeling for the identified geoclutter mechanisms from Charles Holland. The acoustic data sets identified for model-to-data comparison by ARL/PSU will be used to provide feedback to NRL-DC for additional model upgrades. A final task for the Phase II base program will be to produce a configuration managed version of the model with corresponding documentation. All four tasks proposed for the Phase II base program have a 24 month period of performance.

The Phase II option program is designed to produce upgraded versions of the model to satisfy particular needs of the AEER program including frequency spread due to interaction with the sea-surface and the ability to simulate beamformed output for EER sensors.

Phase I Option Tasks

Option Program Task 1 –Identification of Key in-water data sets for Phase II model evaluation/development and Model Implementation of Selected Clutter Mechanisms

Under the Phase I Option Program task 1, key in-water data sets will be identified that will be used under the Phase II model evaluation/development effort. Criteria for selecting the data sets include: measured reverberation time series with a significant clutter feature; supporting environmental data including bathymetry; water column as well as seabed scattering and reflection data. Local (close-range) scattering from the clutter event is also highly desirable and may be available for some runs. We will want to select several data sets, in differing environments, with differing clutter features.

Option Program Task 2 –Configuration Management of Selected Modeling Approach

Under the Phase I Option Program task 2, PSI will work with representatives of both the AEER and LAMP programs to determine their exact needs to interface the broadband time series model to be developed. It is important prior to beginning the Phase II tasking that the software design is documented so that all participants know the design goals of the work. An outline for the model documentation that provides detailed information on all inputs and outputs will also be generated. As funding permits during the task, this outline will be flushed out with details on the model under development. The need for OAML approval or an independent V&V (validation and verification) of the model at the end of the Phase II development will also be explored.

Option Program Task 3 – NRL-DC Model Implementation of Selected Diffuse Reverberation and Discrete Clutter Models

Under the Phase I Option Program task 3, Kevin LePage as an outside resource will continue to implement the selected aspects of the diffuse reverberation and discrete clutter models into his model. The details of the current modeling and future modeling improvements were highlighted in the Phase I summary report.

Phase II Base Program Tasks

Phase II Base Program – Task 1 – Model Additional Mechanisms Responsible for Discrete, Target-Like Clutter Returns in the Littoral Environment

Analysis of two clutter events in the 1998 reverberation data set conducted yielded very valuable information about the clutter mechanisms (scattering from sediment-entrained gas and scattering from gas plumes in the water column) and their spectral and temporal characteristics. That data set exhibited a number of other clutter features that were not analyzed. Coupled with data from 2000 and 2002, not yet analyzed, these data provide a rich observational set from which to characterize additional clutter mechanisms. It will be crucial to analyze all of the significant clutter mechanisms to provide the development of model with as much realism as possible. Costing for task 1 is $124,000 with work performed by Charles Holland (ARL/PSU).

Phase II Base Program – Task 2 – Further Development on the Modeling Approach for Diffuse Reverberation and Discrete Clutter to Satisfy Simulation Requirements

Under the Phase II base program task 2, Kevin LePage as an outside resource will be responsible for the continued development of his broadband discrete clutter and diffuse reverberation modeling. In conjunction with Charles Holland (ARL/PSU), Kevin LePage will implement the modeling for the discrete clutter mechanisms identified by Dr. Holland within the framework defined in this report. Kevin LePage will also serve as an outside expert on the model-to-data comparisons conducted during the Phase II base program task 3. Feedback from the model-to-data comparisons will provided to Kevin LePage during the entire Phase II base program.

Phase II Base Program – Task 3 – Rigorous Model-to-Data Comparisons using Reverberation Data and Concomitant Environmental Characterization

A frequently insurmountable problem in comparing a reverberation model against measurements (even for diffuse reverberation) is having sufficient control over the inputs. Diffuse reverberation decay depends on many environmental factors including bathymetric, water column, and (often dominated by) seabed forward reflection and scattering strength variability. Without knowing each of those components a model-to-data comparison may simply become an exercise in turning knobs. For example, reverberation decay depends upon both bottom reflection loss and scattering in ways that are often indistinguishable so that without independent measurements of those quantities a meaningful model evaluation is impossible.

Model-to-data comparisons for clutter are even more complex. It is not only necessary to have controls on the seabed reflection and seabed scattering but high-resolution geoacoustic information at and near the clutter site and spatial and geoacoustic characteristics of the geoclutter feature are also required. ARL-PSU has several data sets that have extensive measurements of seabed reflection and scattering in the northern Tyrrhenian Sea, the Straits of Sicily (Malta Plateau) and the New Jersey Shelf, for the explicit purpose of providing such controls. These data sets also have close-range measurements of clutter characteristics and high-resolution seabed geoacoustic properties that will be crucial for evaluating and development of the model. We believe that our team (ARL/PSU, NRL-DC and PSI) has a unique capability in this arena to provide meaningful model-to-data analyses.

In this task, ARL-PSU will analyze the acoustic data to provide the required geoacoustic inputs to the reverberation model. Both PSI and NRL-DC will perform model-to-data comparisons to investigate the ability of the simulation to replicate the observed acoustic data. The feedback from the comparisons will be provided to NRL-DC and further refinement of the model (Phase II base program task 2). Model-to-data comparisons will include both basic comparisons for the diffuse reverberation modeling and statistical measures of the time series for both discrete clutter and diffuse reverberation. Costing for task 3 is $241,000 with $116,000 for Charles Holland (ARL/PSU) and $125,000 for Peter Neumann (PSI) and Greg Muncill (PSI.

Phase II Base Program – Task 4 – Configuration Management and Documentation of Modeling Approach for Use in Existing and Future Active Sonar Simulators

The Phase II base program task 4 will transform the Matlab modeling code provided by Kevin LePage (Phase II base program task 2) into a configuration managed model for use by those programs identified during the Phase I and Phase II period of performance. The configuration management will include writing the required software interfaces to connect the model with the simulations in use by the various programs and will provide complete documentation. Costing for task 4 is $135,000 with work performed by Peter Neumann (PSI).

Phase II Option Program Tasks

Phase II Option Program – Task 1 – Modeling of Frequency Spread due to Surface Scattering

Under the Phase II option program task 1 the ability to model the frequency spread resulting from the interaction with the air-water interface and the near-surface bubble clouds will be added to the model developed under the Phase II base program. The approach does not look to conduct basic research on this effect but looks to transition the results developed to date (including those from NRL-DC) into the model. There is an internal funding proposal within NRL-DC for research into this effect that would start in FY 05. If this task were exercised near or at the completion of the Phase II period of performance, the results from this research at NRL-DC could also be leveraged into the model. Costing for the Phase II option task 1 is $200,000 with work performed by Peter Neumann (PSI) and Greg Muncill (PSI) over a 12 month period of performance starting near or at the completion of the Phase II base program.

Phase II Option Program – Task 2 – Integration of Beamforming Algorithms Specific to NAVAIR's EER Program

Under the Phase II option program task 2 the ability to provide beamformed output for the various sensors in the EER program would be added to the model developed under the Phase II base program. This task represents a small task but would add a capability that is of great value to the AEER program. The beamforming routines for all EER sensors would be added to the configuration managed model in a manner consistent with the needs of the AEER program. Costing for the Phase II option task 2 is $50,000 with work performed by Peter Neumann (PSI) over a 3 to 6 month period of performance starting at or near the completion of the Phase II base program.

Key Personnel for the Phase I Option Tasks and Phase II Base and Option Tasks

The personnel proposed for the Phase I option and Phase base and option tasks are the same team that produced the results presented in the Phase I summary report. Peter Neumann of PSI will be the principal investigator with experience in transitioning products developed under SBIR contracts into products submitted for OAML approval. Charles Holland of ARL/PSU provides the team with an expert in the field of geoclutter. Kevin LePage of NRL-DC provides the team with an expert in the field of both diffuse reverberation and discrete clutter modeling.

Phase III Commercialization Opportunities

During the Phase I base program, two potential transitions for the simulation proposed for development under the Phase II work plan were identified. In a meeting with Rick Fillhart[1] of the EER program and Dave Fenton[2] of the LAMP program on December 11th, 2003, the application for this type of simulation product within each of these programs was evident if it could satisfy their specific program's requirements. The proposed Phase II option tasks address some specific requirements of the AEER program that were brought out during that meeting. The proposed simulation tool, capable of producing realistic, broadband time series predictions including the effect of target-like clutter would be a valuable tool for use in active sonar system design. The ability to accurately simulate broadband time series for a hypothetical source/receiver before doing in-water testing should allow for a more cost effective design and allow the in-water testing that is done on more mature designs. Currently there is no tool capable of simulating broadband time series in littoral environments in the frequency range of 5 KHz below. It was also stated at the meeting with the EER and LAMP program representatives that there is no simulation initiative to be started during the time frame of this Phase I and Phase II STTR.

Company Strategy and Intellectual Property

PSI is a thirty-year old, high technology company concentrating significant effort in commercializing SBIR, STTR and acquired technologies for the open market. Three examples of technologies well along in the process of commercialization are the Hybrid Adaptive beamformer, an assistive listening technology for the hearing impaired and computer appliances markets, the SECURES®, an urban gunshot detection system for police crime mapping use, and the Space-system Adaptive Vibration Control, neural net controlled sensor arrays for vibration damping of lightweight space-based systems. Peter Neumann of PSI is currently transitioning acoustic inversion software developed under an ONR SBIR award into a SPAWAR product, GAIT, being submitted for acceptance into OAML in 2004.

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